SECTION 3.0
SUMMARY OF 1997
MONITORING DATA

This section summarizes both ambient and point source monitoring data for 1997. A total of 21 ambient stations and 25 point source stations were sampled in 1997. Also included is a summary of 1997 precipitation data as pollutants, particularly fecal coliform bacteria, are introduced into intertidal and subtidal waters following rainstorms. All data for stations monitored are presented in appendices A through E. Station locator maps are provided in Section 2.0.

3.1 1997 PRECIPITATION DATA

The monthly total precipitation for Seattle in 1997 is shown in Figure 3-1. For comparative purposes, precipitation totals do not include snow or ice pellet accumulations as the 30 year average does not include these data. The numbers were obtained from the National Climatic Data Center for the Sea-Tac International Airport station (NOAA, 1997). The total precipitation in 1997 was 43.3 inches (in.), which was 3 in. more than the five year average, 6 in. more than the 30 year average but 18 in. less than the 1996 total. March (8.2 in.) and January (7.0 in.) had the highest amount of rainfall which accounted for 35% of the total rainfall for 1997. Less than six inches of rain fell between May and August.

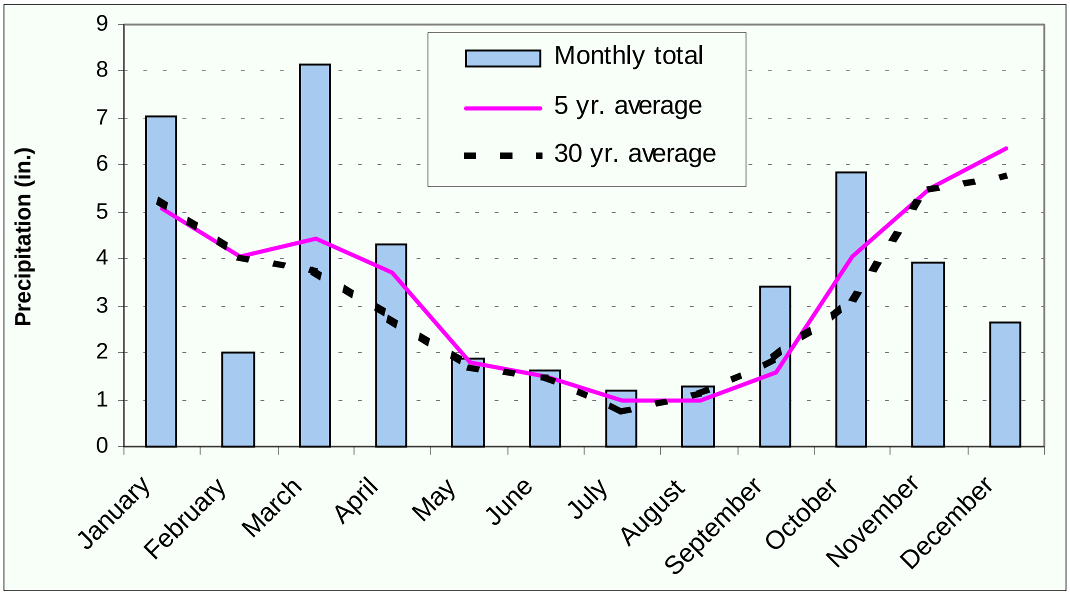

Figure 3-1. Monthly Precipitation for 1997

3.2 MONITORING RESULTS

Results of ambient and point source monitoring are contained in Appendices A through E. A summary of the results obtained for specific parameters (e.g., salinity, temperature, bacteria) and matrices (e.g., water, sediment, shellfish) are provided in this section. The results for ambient and point source samples are combined in order to facilitate the interpretation of results in this section.

Water Column Data

Water column sampling is an important component of King County's water quality monitoring program and includes both subtidal (offshore) and intertidal sampling sites (see Figures 2-1 and 2-2). The monitoring program is structured to detect natural seasonal changes in the water column as well as identify changes from anthropogenic input (human-related sources).

Water column samples were sampled for temperature, salinity, transparency (water clarity), total suspended solids, dissolved oxygen, silica, chlorophyll-*a*, nutrients, and bacteria.

Results

Water quality parameters, including temperature, salinity, secchi disk transparency, total suspended solids, dissolved oxygen, silica, chlorophyll-*a*, nutrients, and bacteria were measured at nine subtidal stations. Water temperature (surface only), salinity, and bacteria were monitored at station KSRU02 located near the Ballard Locks in the Lake Washington Ship Canal.

Unfortunately, samples were not collected for certain months—January, March, April, June, and August. Therefore, a thorough discussion regarding seasonal trends is not possible for 1997.

Water Temperature Depending upon the depth of the station, temperatures were monitored at one to seven depths. Depths ranged from just below the surface down to 200 m (656 ft). For all stations, temperatures ranged from 7.2 to 16.3 (mean = 11.5) ^{o}C. Values for six stations, located off Point Jefferson, Point Wells, off the West Point Treatment Plant (TP) outfall, inner Elliott Bay, off the Alki TP outfall, and off Dolphin Point, are shown in Figure 3-2 and are representative of the pattern shown at other stations sampled. Temperature variations during the winter months were slight, particularly at greater depths. Surface water temperatures varied more than samples taken at deeper depths due to various weather influences, such as air temperature, cloud cover, and wind. The water column started to exhibit weak thermal stratification in May. However, due to the lack of data during the summer and early fall, the duration of the stratification was not able to be determined.

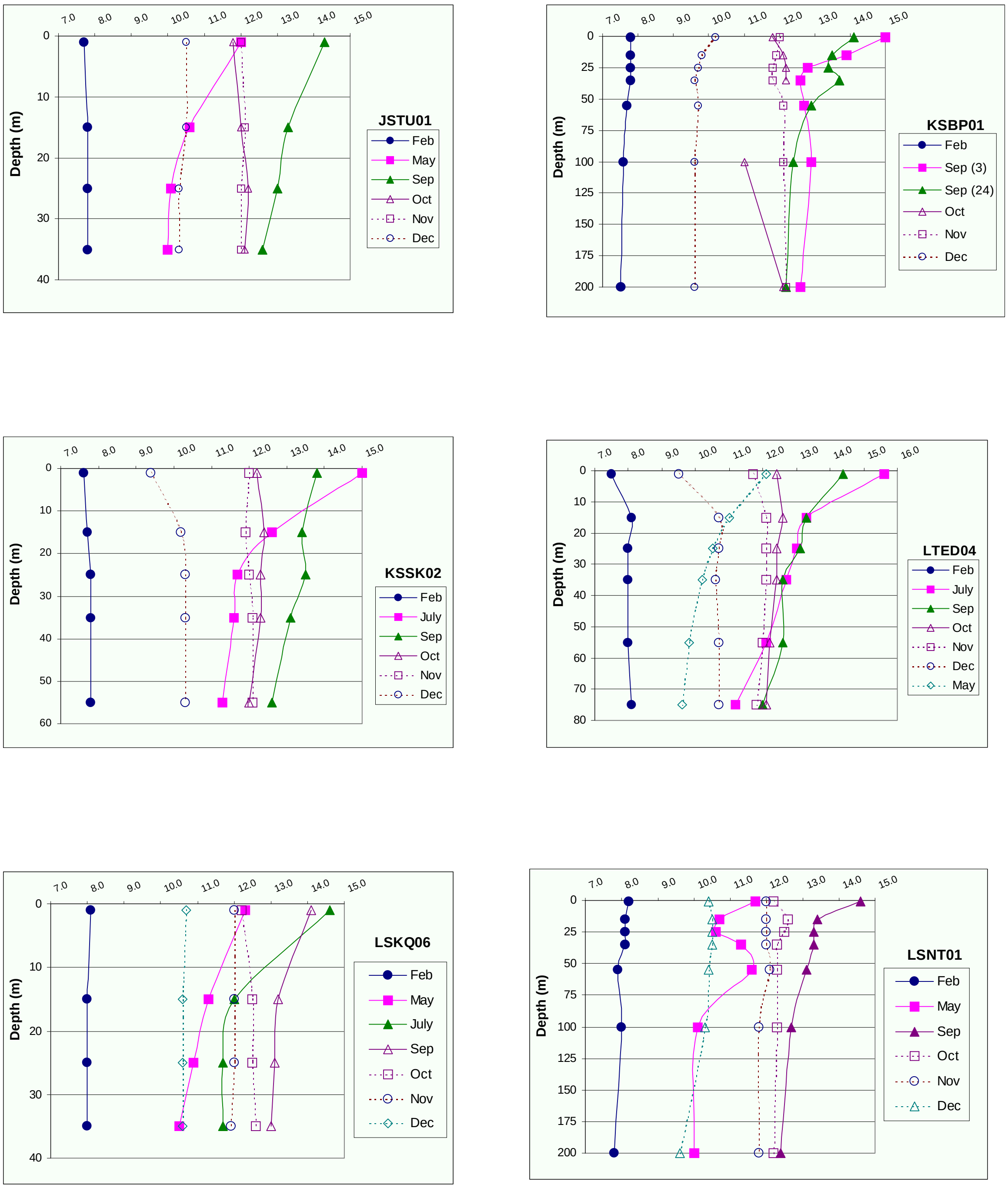

Figure 3-2. Water Temperature at Six Stations (^oC)

Water temperatures for all depths measured over a six year period, from 1992 to 1997, are shown in Figure 3-3 for stations KSBP01 and LSNT01. The figures indicate a well-mixed water column throughout most of the year with no development of a thermocline (characterized by a rapid decrease in temperature with increased depth). There is, however, a noted rise in surface water temperatures during the summer months which corresponds to a rise in air temperature and an increase in solar radiation. Between May and October (months with the warmest temperatures), the mean for stations KSBP01 and LSNT01 between 1992 and 1997 was 11.9 ^{o}C for all depths. This is similar to a mean of 12.6 ^{o}C for 1997 only. Between November and April (months with the coldest temperatures), the mean was 9.0 ^{o}C for all depths between 1992 and 1997. This is lower than the mean of 10.0 ^{o}C for 1997 but only three months of data were included in the 1997 mean.

Salinity Salinity was measured at seven depths ranging from 1 to 200 meters, depending upon the depth of the station. Salinities ranged from 17.40 to 32.77 (mean = 28.89) practical salinity units (psu) for all stations except KSRU02. Station KSRU02 is located in the Lake Washington Ship Canal and the salinity at this station is tidally influenced and ranged between 10.61 and 22.42 psu. Salinities varied due to seasonal influences as well as time sampled (eg., ebb vs. flood tide).

Salinity profiles for six stations are shown in Figure 3-4. Lower salinities were detected in surface waters during winter months when freshwater input is highest. Unlike surface waters, salinities measured at depths of 15, 25, 35, 55, 100, and 200 m showed little variation with depth. Mean values ranged from 29.07 (15 m) to 29.69 (100 m) and indicates a well-mixed water column. Salinities increased in July which may be attributed to an increased input of salitier deep oceanic water due to off-coast upwelling during late summer and a decrease in freshwater input from rivers and precipitation. However, a decrease at 25 m was noted at all the stations sampled in July which is an unusual occurrence and has not been seen in previous years. It is not clear why this occurred.

Salinities measured from 1992 to 1997 for stations KSBP01 and LSNT01 are given in Figure 3-5. The figures show a well-mixed water

Figure 3-3. Water Temperature Variations from 1992-1997 (black dots indicate sample points)

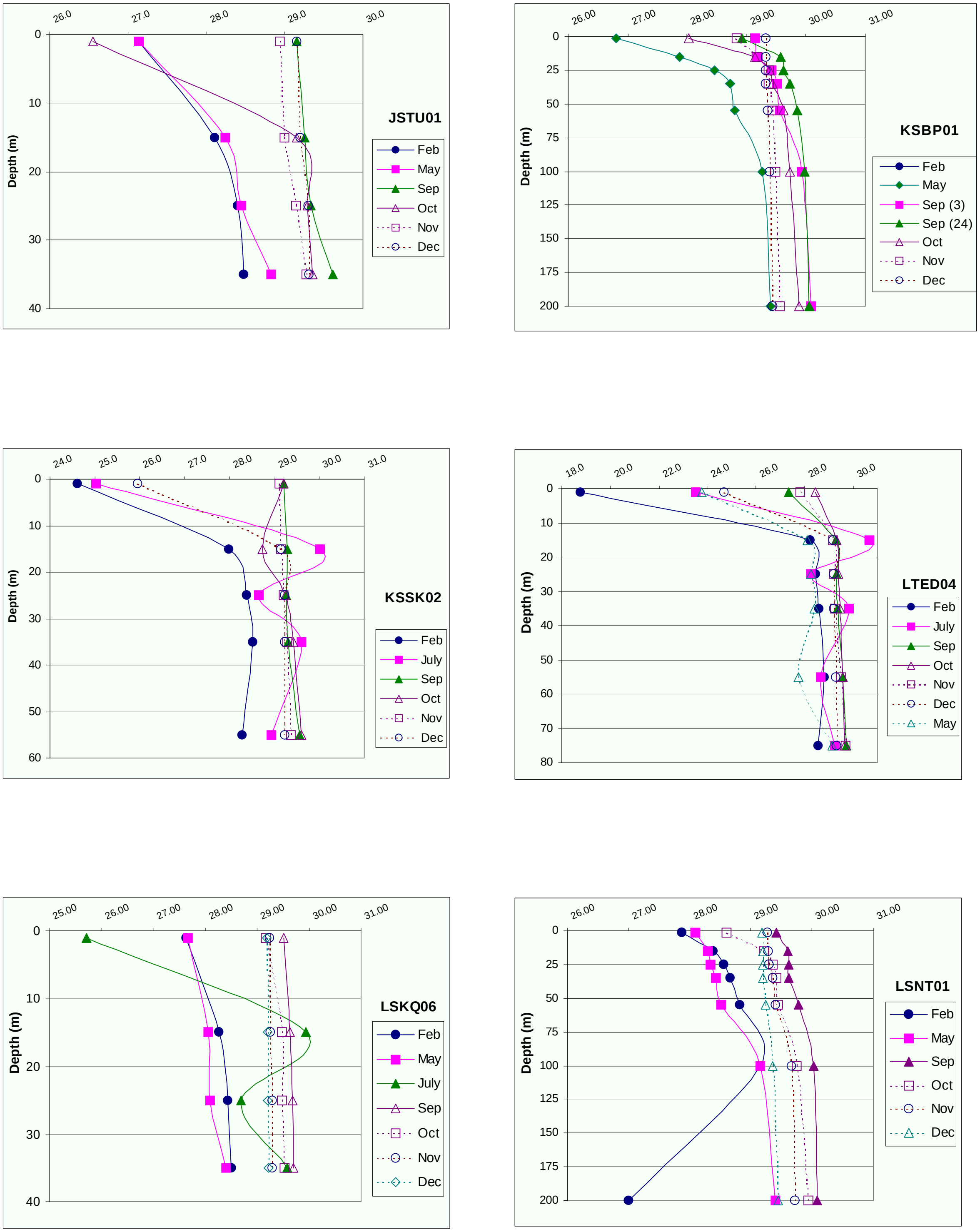

Figure 3-4. Salinities at Six Stations (psu)

Figure 3-5. Salinity Variations from 1992-1997 (black dots indicate sample points) column with no development of a strong halocline (characterized by a rapid increase in salinity with increased depth).

Transparency Secchi disk depth (transparency) values ranged from 1.0 to 12.0 m for all stations. The lowest values were observed during months when freshwater runoff was high and months when phytoplankton blooms occurred. Lowest values at the two inner Elliott Bay stations were noted in February when high flows from the Duwamish River into Elliott bay caused turbidity. at stations were observed during February when freshwater runoff was highand May. In May, the decrease in water clarity may be attributed to a phytoplankton bloom, as evidenced by the increased chlorophyll-*a* values. Transparencies were highest in June at all stations with the exception of KSRK02. Station KSRK02 had the greatest water clarity in August but was still relatively clear in June.

Transparency values for stations KSBP01 and LSNT01 tended to be higher in 1996 than those in 1995. January was the exception to this with values in 1995 approximately 2 m (6.6 ft) greater than in 1996.

Total Suspended Solids Total suspended values ranged throughout the year from 0.6 to 30.7 (mean = 4.6) mg/L. Generally, values tended to be higher at the lowest depth measured for those stations deeper than 55 m due to resuspension of bottom sediments. This was not the case, however, for stations 55 m or less. The mean for surface values at all stations throughout the year was 5.1 mg/L, which is slightly higher than the means obtained from other depths (4.3 to 4.5 mg/L). During the months when chlorophyll-*a* levels were elevated (usually May July, and September), suspended solids values were higher at the surface. This is due to the influence of phytoplankton particles. Suspended solids are measured by filtering a well-mixed water sample through a glass-fiber filter and trapping suspended particles on the filter. Large phytoplankton particles are also trapped on the filter and can cause higher total suspended solid values when phytoplankton are abundant.

There was no difference in mean values observed from station to station, even for the two stations located in inner Elliott Bay, LTBC40 and LTED04. The mean for both of these stations throughout the year was 4.6

mg/L and for stations located at the West Point Treatment Plant outfall (KSSK02) and the central basin (LSNT01) the means were also 4.6 mg/L.

Although, total suspended solids were only measured at stations KSBP01 and LSNT01 prior to 1997, values for these stations in 1997 were similar to those obtained in previous years.

Dissolved Oxygen Depending upon the depth of the station, dissolved oxygen was measured at three to seven depths. Depths ranged from just below the surface down to 200 m. Dissolved oxygen concentrations ranged from 4.7 to 12.6 (mean = 7.2) mg/L for all stations sampled in 1997. Concentrations decreased with depth and is expected as input from the atmosphere across the air-sea interface and photosynthetic activity yield most of the dissolved oxygen in estuaries (Kennish, 1994). Figure 3-6 shows dissolved oxygen profiles for six stations sampled in 1997.

Dissolved oxygen values were below 7.0 mg/L from October to November at most depths and stations. Dissolved oxygen concentrations below 7.0 mg/L occur naturally during late summer and fall due to the input of deep oceanic water which contains low amounts of oxygen. During the summer months, surface water oxygen concentrations are greater than 7.0 mg/L, however, concentrations decrease with increasing depth. This is due to warmer water temperatures which contain less oxygen and no photosynthesis from phytoplankton at these depths.

Washington State marine surface water quality standards for dissolved oxygen vary depending upon the intended water use and classification of the waterbody. Ecology uses a dissolved oxygen value of 5.0 mg/L as a guideline to indicate where potential problems could occur (Ecology, 1998). Concentrations for all stations were above this guideline with two exceptions. Stations JSTU01 and KSSK02 had values of 4.9 and 4.7 mg/L, respectively, near the surface in December. An inch and a half of

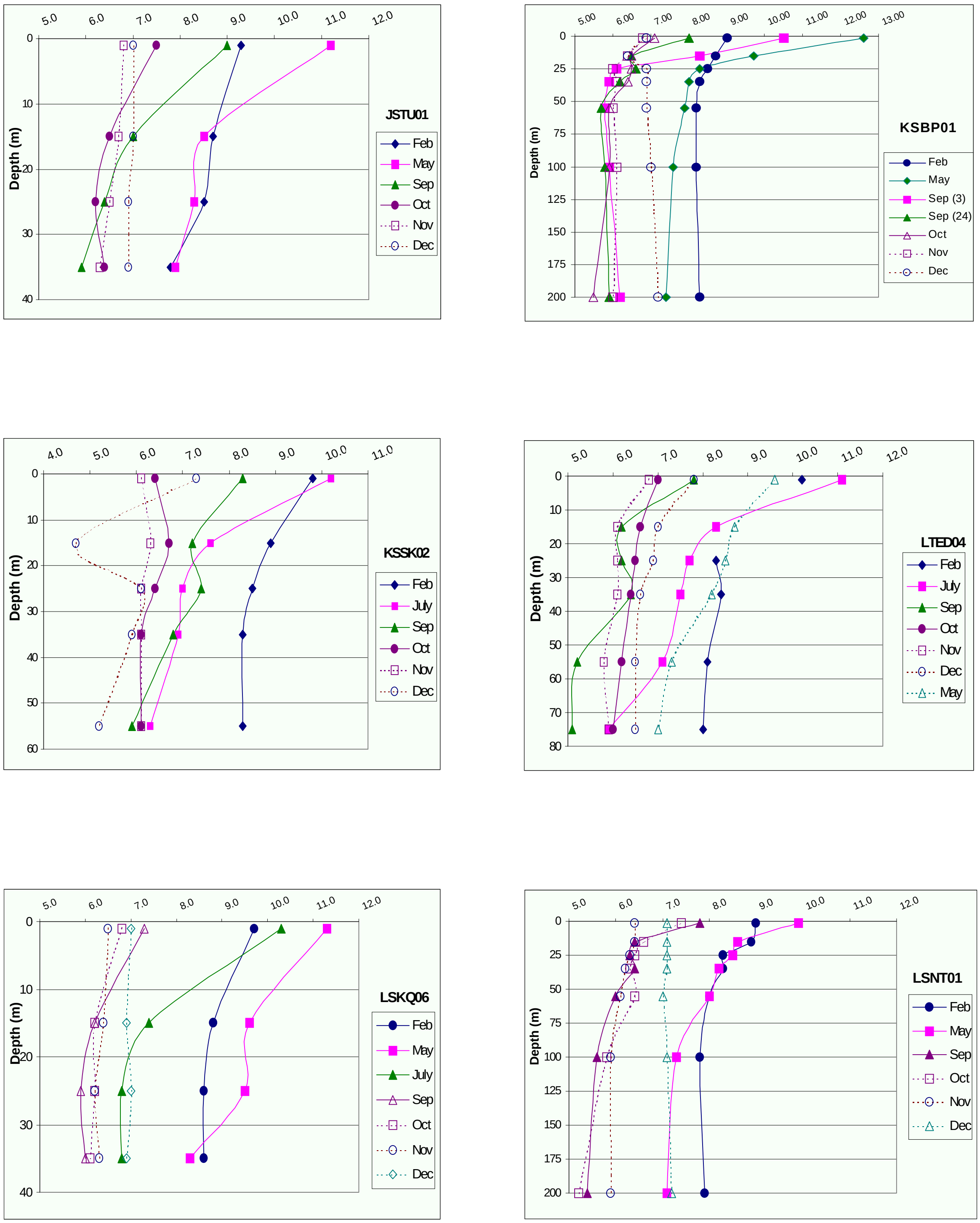

Figure 3-6. Dissolved Oxygen at Six Stations (mg/L)

rain fell in the two days prior to sampling and it is possible that an increase in particulates from the rain caused a decrease in oxygen due to oxidation of the organic matter.

Dissolved oxygen values measured at stations KSBP01 and LSNT01 between 1992 and 1997 ranged from 4.7 to 15.0 mg/L (Figure 3-7). Mean concentrations from 1992 and 1996 were similar, however, mean concentrations for 1997 were slightly lower than previous years. This could be attributed to the El Ni⁄o event in 1997 and warmer water temperatures.

Silica Silica was measured at all stations and depths. Concentrations ranged from 0.45 to 5.9 mg/L with a mean of 2.8 mg/L. Values at the surface and 15 m were slightly lower than values from other depths measured as diatoms (microscopic photosynthetic plants) use silica for skeletal growth and are usually concentrated near the surface. Further evidence that silica concentrations are biologically related was seen in winter. Winter months (November, December, and February) had higher mean and maximum concentrations when phytoplankton abundance is low and silica uptake is at a minimum. The two stations in Elliott Bay, LTBC41 and LTED04, had slightly higher mean and maximum concentrations than other stations, which may be attributed to the influence of the Duwamish River.

Silica concentrations in 1997 were similar to concentrations found in 1995 and 1996.

Chlorophyll-a and Phaeophytin Chlorophyll-*a* and phaeophytin were monitored at nine stations and at four depths (1, 15, 25, and 35 m). Chlorophyll-*a* values ranged from 0.01 to 55.8 µg/L (mean concentration was 2.2 µg/L) and phaeophytin levels ranged from <0.01 to 18.7 µg/L (mean concentration was 0.40 µg/L).

Figure 3-7. Dissolved Oxygen Variations from 1992-1997 (black dots indicate sample points)

Although it is difficult to assess chlorophyll results as data was only collected for seven months (six for some sites), in general chlorophyll-*a* and phaeophytin levels were low in the winter and decreased with depth for all months. This corresponds to the decreased light availability for plant growth at deeper depths. High chlorophyll-*a* levels at the surface in May, July, and September indicated a bloom occurred. When blooms occurred, the highest chlorophyll values were found at the stations in inner Elliott Bay, LTBC41 and LTED04. The water column is not as well mixed at these two stations as the other stations sampled, which is a contributing factor to the high values detected.

Several factors influence chlorophyll concentrations, including availability of light and nutrients, air temperature, and zooplankton grazing. As stated in the previous chapter, phaeopigments such as phaeophytin are degradation products of chlorophyll produced when zooplankton graze on phytoplankton cells. The highest phaeophytin concentration was found at station LTED04 in July when a summer bloom had occurred. Generally, phaeophytin values tended to be higher below 15 m than at the surface and when chlorophyll concentrations were also high. Overall, phaeophytin concentrations at the two inner Elliott Bay stations were not higher than other stations as this parameter is affected more by zooplankton abundance than by water column mixing.

Chlorophyll-*a* values measured in 1997 were similar to results obtained from previous years. Although maximum concentrations vary from year to year, phtyoplankton blooms exhibit seasonal trends with blooms usually occurring in May and July.

Nitrogen Compounds Several forms of inorganic nitrogen are commonly found in the marine environment. These compounds include ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-), with nitrate being the primary form of inorganic nitrogen in seawater. The analytical method that the King County Environmental Laboratory uses to measure nitrate concentrations does not distinguish between nitrate and nitrite, therefore, these two forms are reported as one value expressed as nitrate+nitrite. Nitrite amounts in the water column are naturally very low and the contribution of nitrite to the total value is usually minimal. Values for total ammonium and total nitrate+nitrite are reported below.

Ammonium. Values ranged from less than the method detection limit (0.02 mg/L) up to 0.27 mg/L for all nine stations monitored. The mean concentration for all stations and months was 0.03 mg/L. Most ammonium concentrations monitored at all depths were at or below the method detection limit except from May through September. Higher concentrations during the summer months are expected as ammonium is generated from the decay of organic nitrogen (both natural and from zooplankton grazing) and peaks about the time of senescence (decay) in the producer growth cycle (Valiela, 1984). A frequency plot of the values obtained for all stations combined is shown in Figure 3-8.

Ammonium concentrations measured in 1997 were similar to those measured in previous years. The two stations which had the highest concentrations, LSEP01 and KSSK02, were not monitored in previous years. Station LSEP01 which is located at the Renton outfall had a concentration of 0.16 mg/L at 150 m and KSSK02 located at the West Point outfall had a concentration of 0.27 mg/L at 55 m. These ammonium concentrations indicates that the effluent plume from the treatment plants were evident at these depths. At both of these sites, only the deepest depth monitored had high concentrations and values at the other depths measured were much lower.

Nitrate+Nitrite. As stated above, nitrate is usually the primary form of inorganic nitrogen in seawater and was most abundant in the winter when it was not taken up by phytoplankton and when freshwater runoff was highest. Phytoplankton uptake is restricted to the photic zone (the zone where enough light penetrates for photosynthesis to occur) which is why nitrate+nitrite concentrations tend to increase at depth. Overall, nitrate+nitrite concentrations ranged from less than the detection limit (0.05) to 0.48 mg/L for all nine stations monitored. There were two instances where

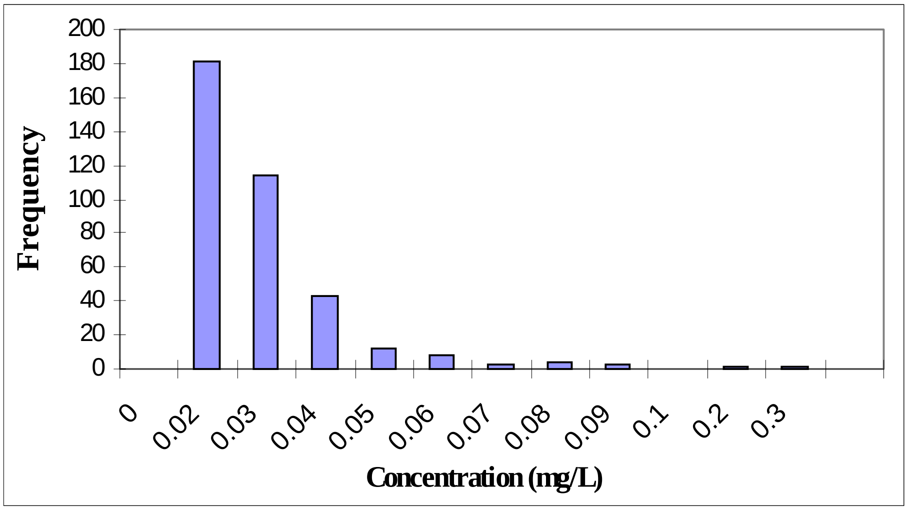

Figure 3-8. Frequency Distribution of Ammonium Concetrations at All Stations Sampled in 1997

concentrations were below the detection limit and both of these occurred at the surface when phytoplankton blooms were evident. Values were similar for all the stations.

Nitrate+nitrite values measured in 1997 were similar to values from previous years.

Phosphorous Phosphorous in seawater is found as dissolved inorganic, dissolved organic, and particulate phosphorous. Generally, particulate phosphorous is the most abundant form. Several forms of inorganic phosphorous are found in the marine environment. The most abundant forms of phosphorous are the orthophosphate ions, with HPO_4^{2-} being the major ion in seawater (Valiela, 1984).

Total phosphorous (which includes all forms of inorganic and organic phosphorous) was measured at nine stations. Values ranged from 0.02 to 0.13 mg/L. Concentrations did not show a clear trend with depth. However, phosphorous did show a clear seasonal trend with levels decreasing in the summer months (May and July) which is due to phytoplankton and bacteria uptake. Concentrations were the highest in

December at all stations. Results obtained in 1997 were similar to concentrations measured in previous years.

Bacteria Fecal coliform and *enterococcus* bacteria were monitored at 10 subtidal water column stations (5 ambient and 5 point source), 21 intertidal water stations. Two freshwater stations, KTHA01 and KSRU02, are monitored and the results from these stations are compared to freshwater bacteria standards. All other stations are compared to saltwater standards. Washington State marine water Class AA fecal coliform standards for surface waters state that organism counts shall not exceed a geometric mean value of 14 colonies/100 ml and not more than 10 percent of the samples used for calculating the geometric mean value may exceed 43 colonies/100 ml. Freshwater Class AA fecal coliform standards state that organism counts shall not exceed a geometric mean value of 50 colonies/100 ml and not more than 10 percent of the samples used for calculating the geometric mean value may exceed 100 colonies/100 ml (WAC 173-201, 1991). King County uses results from the 30 most recent samples (surface samples only) to obtain a geometric mean value as per the guidelines in the National Shellfish Sanitation Program (NSSP, 1995).

Enterococcus bacteria standards do not currently exist in Washington State. It is possible that this organism will be used as an indicator of the presence of pathogenic bacteria in the future, therefore, King County will continue to monitor the levels of this organism. *Enterococcus* data are presented in Appendix A but will not be discussed further.

Fecal Coliform Bacteria. All the subtidal stations met Class AA marine water standards for fecal coliform bacteria with the exception of one station, LTBC40, located near the Denny Way CSO in inner Elliott Bay (Tables 3-1 and 3-2). The levels at this station met the peak standard but was just above the geometric mean standard of 14 cfu/100 ml. It should be noted that for this station, as well as several others, the geometric mean was calculated using less than 30 samples as 1997 was the first year of sampling at these sites. The geometric mean was 14.3 at this station and most values were below 10 cfu/100 ml except for three months. The freshwater station in the Lake

Washington Ship Canal met Class AA freshwater fecal coliform standards.

Table 3-1. 1997 Ambient Monitoring—Fecal Coliform Bacteria

Station	Meets Class AA Marine Water Standards: Geometric mean (14 colonies/100 ml)	Peak [a] (43 colonies/100 ml)	Comments
Intertidal			
Stations north of Ship Canal			
KSQU01	No	No	Station is just north of the Ship Canal.
KSLU03	No	No	Station is at the north end of Golden Gardens by marina.
KRJY01	Yes	Yes	Only sampled from May to September.
JSWX01	Yes	Yes	Station is south of fuel docks at Richmond Beach.
JSVW04	Yes	No	Geometric mean was close to standard for Nov. and Dec.
Stations between Ship Canal and Alki Point			
KSYV02	No	No	Station is near Magnolia Park.
LTAB01	No	No	Located near fishing pier in Elliott Bay Park.
LTEH02	No	No	Station is near Pier 48 in inner Elliott Bay.
LSGY01	Yes	Yes	Geometric mean was calculated using less than 30 samples.
LSFX01	Yes	Yes	Geometric mean was calculated using less than 30 samples.
LSHV01	Yes	Yes	Located north of Alki Point near Alki Drive.
Stations south of Alki Point			
LSVW01	No	No	Located north of ferry dock in Fauntleroy Cove.
LSTU01	Yes	No	Station is near Lincloln Park.
MTEC01	Yes	No	Only sampled from May to September.
MSSM05	No	No	Only sampled from May to September.
Subtidal			
Point Jefferson			
KSBP01	Yes	Yes	Station is between Carkeek Park and Jefferson Head.
Ship Canal			
KSRU02 [b]	Yes	Yes	Station is located in the Lake Washington Ship Canal.
Point Wells			
JSTU01	Yes	Yes	Station is just offshore from Point Wells.
Elliott Bay			
LTED04	Yes	Yes	Station is lcoated in inner Elliott Bay.
Dolphin Point			
LSNT01	Yes	Yes	Station is between the north tip of Vashon Island and Fauntleroy Cove.

[a] -- Not more than 10 percent of the 30 most recent samples may exceed this value.

[b] -- Station results are compared with Class AA freshwater standards which state the geometric mean value may not exceed 50 colonies/100ml and not more than 10 percent of the most 30 recent samples may exceed 100 colonies/100 ml.

Table 3-2. 1997 Point Source Monitoring—Fecal Coliform Bacteria

Station	Meets Class AA Marine Water Standards: Geometric mean (14 colonies/100 ml)	Meets Class AA Marine Water Standards: Peak [a] (43 colonies/100 ml)	Comments
Intertidal			
Carkeek Park			
KSHZ03	No	No	Station is near the mouth of Piper's Creek.
KTHA01 [b]	No	No	This is a freshwater station in Piper's Creek.
West Point			
KSSN04	Yes	No	Located north of the West Point lighthouse.
KSSN05	Yes	No	Exceeded geometric mean standard January -- May.
Alki Point			
LSKR01	No	No	Station is at Alki Point.
LSKS01	No	No	Located south of Alki TP outfall.
Subtidal			
Carkeek Park			
KSIW02	Yes	Yes	Geometric mean was calculated using less than 30 samples.
West Point			
KSSK02	Yes	Yes	Geometric mean was calculated using less than 30 samples.
Denny Way			
LTBC40	No	Yes	Geometric mean was calculated using less than 30 samples.
Alki Point			
LSKQ06	Yes	Yes	Station is just off the Alki TP outfall.
Renton outfall			
LSEP01	Yes	Yes	Station is just off the Renton TP outfall.

[a] -- Not more than 10 percent of the 30 most recent samples may exceed this value.

[b] -- Station results are compared with Class AA freshwater standards which state the geometric mean value may not exceed 50 colonies/100ml and not more than 10 percent of the most 30 recent samples may exceed 100 colonies/100 ml.

Fecal coliform bacteria in the water column near King County's treatment plant discharges were found at low levels if detected at all. Most subtidal stations had higher levels in December at all depths when one and a half inches of rain fell two days prior to sampling. For the subtidal stations, the highest bacteria levels are usually seen at the surface samples.

Fecal coliform levels in water samples taken from intertidal beaches are influenced by freshwater runoff from the surrounding watersheds that drain into the Sound. As a result, the number of stations exceeding the Class AA marine standards increased in the high rainfall months and at stations closer to streams and other sources of freshwater runoff. Also, restricted bays and areas removed from the strong tidal mixing of the open Sound tend to retain freshwater inputs for a longer period of time. Therefore, stations located near these geographic areas, such as station MSSM05 near the Tramp Harbor fishing pier and LSVW01 in Fauntleroy Cove, had higher bacteria levels.

The intertidal beaches with the lowest fecal coliform levels were those near Seacrest Park, Duwamish Head, and the station located between Duwamish Head and Alki Point. Bacteria levels at these three stations were below Class AA marine water standards. The exposed Bainbridge Island beach station at Fay Bainbridge State Park and the southern station at Richmond Beach also met Class AA marine water standards.

Several beaches met the geometric mean standard but failed the peak standard; these included the two West Point stations, Lincoln and Seahurst Park stations, and the northern Richmond Beach station. Counts over 43 cfu/100 ml during the summer months were detected at the northern Richmond Beach station (JSVW04) and may be due to waterfowl waste, however, the source is not apparent. Both West Point stations only exceed the peak standard once in 1997 but several values in 1996 that make up the 30 most recent results exceeded the standard. The Lincloln Park station (LSTU01) exceeded the peak standard during months with increased freshwater input.

Beaches that exceeded both the geometric mean and peak standards were in the Carkeek Park area, south side of Alki Point, Shilshole Bay, Magnolia, inner Elliott Bay, Fauntleroy Cove, and Tramp Harbor (Figure 3-9). These stations have consistenly failed Class AA standards over the past several years. These stations are either located near a freshwater source or in areas with poor flushing where fecal coliform levels are elevated. Counts at these stations increased following periods of rainfall from late summer to early winter and also in the summer when waterfowl and dogs tend to congregate at

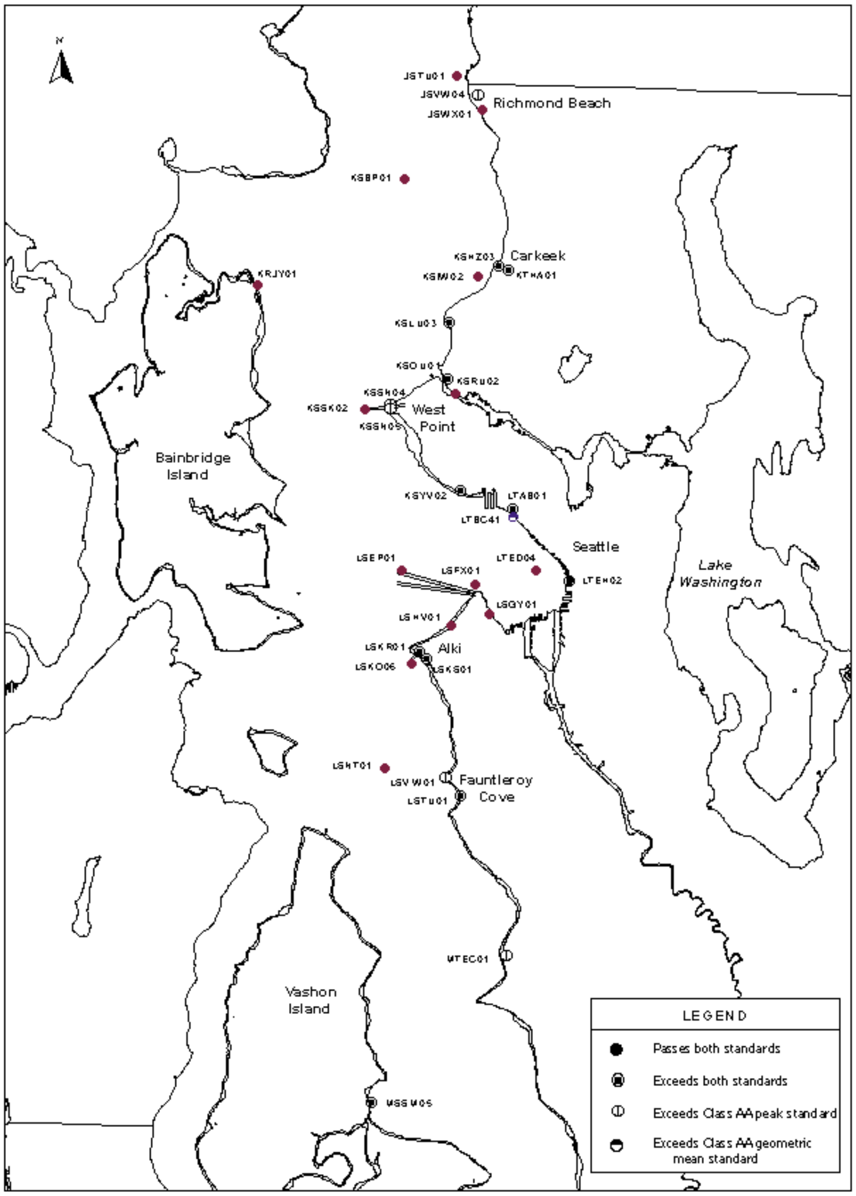

Figure 3-9. Fecal Coliform Stations and Results

beaches such as Carkeek Park and Golden Gardens. Although rainfall increased during winter and spring, coliform counts did not increase accordingly. This is most likely due to colder temperatures inhibiting growth and that samples were taken once a month and not continuously throughout the month which would reflect freshwater input more appropriately.

Sediment Chemistry Data

Subtidal and intertidal sediments were sampled as a part of the ambient and point source monitoring programs (see Figures 2-1 and 2-2). Sediments were sampled for conventional parameters (total solids, total volatile solids, total sulfide, oil and grease, total organic carbon, and grain size distribution), metals, and organic compounds. Metals and ionizable organics data are presented on a dry weight basis and non-ionizable organics data are presented on both a dry weight and organic carbon normalized basis. All sediment data are provided in Appendix B.

Results

A total of 15 subtidal sediment sites (all point source) were sampled for sediment conventionals, metals, and organic compounds. Six intertidal stations (three ambient and three point source) were sampled for conventionals, metals, organic compounds, and bacteria.

Conventionals Total sulfides were measured at the 15 subtidal point source stations. Total sulfides are monitored as they may be toxic to benthic organisms, create unaesthetic conditions, and affect the toxicity of certain metals. Sulfides ranged from less than 10.0 mg/kg up to 130 mg/kg (station RT625SD). Sulfides were only detected at one of the Alki stations but at all the Renton outfall stations. Besides the station with a value of 130 mg/kg, values at the other Renton outfall stations were below 68 mg/kg. The station located near Denny Way in inner Elliott Bay had a value of 92 mg/kg. Sulfides tend to be higher in areas with greater amounts of freshwater input which can restrict water column mixing.

Total oil and grease includes compounds such as hydrocarbons, animal fats, vegetable oils, soaps, and greases. This analysis was conducted on both subtidal and intertidal sediments. Total oil and grease values ranged between 260 and 980 mg/kg. Values were slightly higher at the Renton outfall stations and at the inner Elliott Bay station. Concentrations were similar between subtidal and intertidal samples.

Total organic carbon (TOC) was measured for all sediment samples. Values ranged from 1,660 to 8,670 mg/kg for subtidal sediments and 234 to 1,730 mg/kg for intertidal sediments. Intertidal sediments are composed mainly of sand and gravel and sandy sediments have lower TOC values than sediments containing a high proportion of silt and clay. The association between TOC, total solids, water depth, and grain size is discussed in more detail below. TOC content at the Alki stations was much lower than other subtidal sediments. The mean concentration for Alki sediments was 1,900 mg/kg as opposed to 8,149 mg/kg for Renton outfall sediments. This is expected as the Alki stations are in relatively shallow waters compared to the other stations and are composed of mainly sand and gravel.

Total organic carbon, total solids, water depth, and grain size are all inter-related variables and Figure 3-10 shows the relationship between TOC and grain size. The amount of organic carbon contained in sediments is directly related to the physical processes that regulate grain size. Higher concentrations of organic carbon and total solids occur with fine-grained sediments in depositional areas, whereas lower organic carbon content and solids occur where coarse-grained sediments are found and organic-rich fines do not accumulate. Fine-grained sediments are generally found at deeper depths and coarse-grained sediments found closer to the shoreline.

Metals Sixteen metals were analyzed at fifteen point source subtidal stations and thirteen metals were analyzed at six intertidal stations (three point source and three ambient). A summary of the metals detected in subtidal sediments is given in Table 3-3. All results are presented on a dry weight basis.

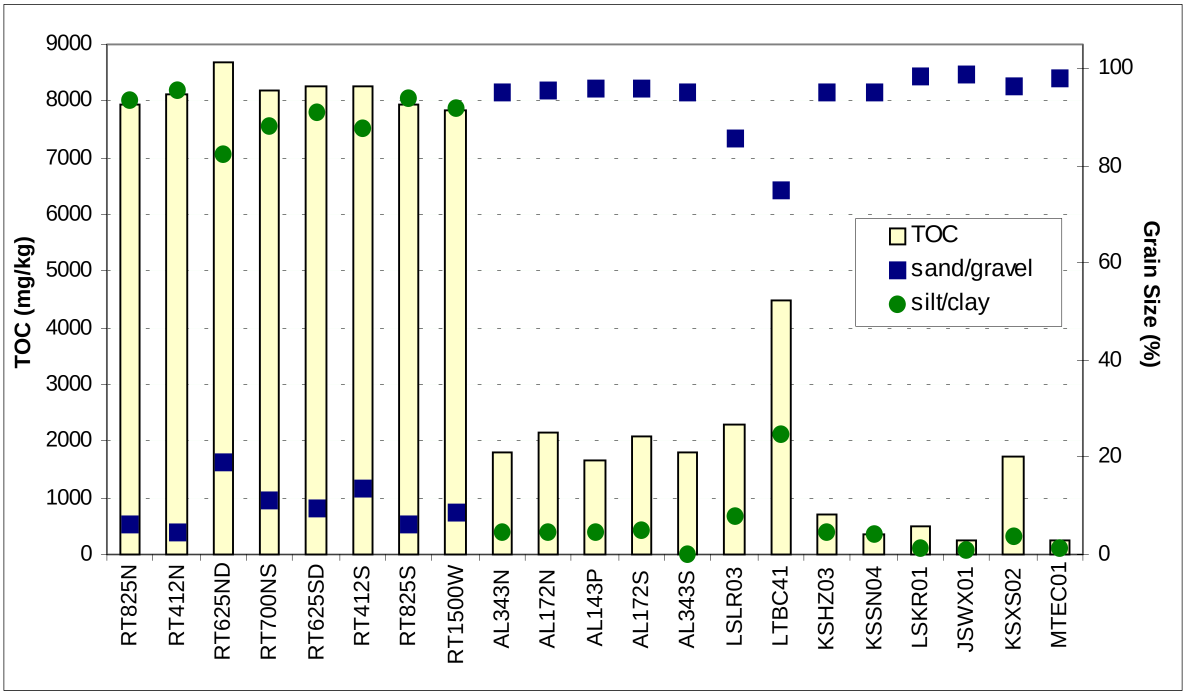

Figure 3-10. Sediment Organic Carbon and Grain Size Data

Four metals, antimony, cadmium, selenium, and thallium were not detected in any samples. Silver was only detected in one sample, LTBC41, which is located in inner Elliott Bay where there is a historical source of silver contamination (Tetra Tech Inc., 1988). Silver is a geologically rare element but can enter the marine environment through mining, smelting, and sewage wastes (Luoma et al., 1995). The value detected was just above the method detection limit and well below the Washington State sediment quality standard (SQS) for silver. Arsenic, chromium, copper, lead, and zinc were detected in all samples, however, concentrations were well below SQSs for these metals. Nickel was also detected in all samples ranging from 13.7 to 38.8 mg/kg but there is no SQS for this metal. Mercury was detected at the stations where silt and clay was the predominate grain size fraction. The Renton outfall stations and the one station in inner Elliott Bay all had mercury values above detection limits whereas the Alki and intertidal stations had no detectable levels. Mercury can enter the marine environment from boat paints, smelting operations, plastics, electrical equipment, and creosote. All detectable mercury concentrations were below the SQS.

Table 3-3. Metals Summary for Subtidal and Intertidal Sediments

	Range (mg/kg dry weight)		Detection Frequency		Station with Highest Value	
	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal
Aluminum	7497 - 23938	na	15/15	na	RT625ND	na
Antimony	<2.0 - <5.0	<1.6 - <1.9	0/15	0/6	---	---
Arsenic	4.0 - 15.2	<2.7 - 3.4	15/15	2/6	RT412S	KSSN04
Beryllium	0.1 - 0.4	0.1	15/15	6/6	8 stations	6 stations
Cadmium	<0.2 - <0.5	<0.2	0/15	0/6	---	---
Chromium	21.8 - 48.9	9.5 - 18.1	15/15	6/6	RT625ND	JSWX01
Copper	6.3 - 46.5	5.8 - 11.4	15/15	6/6	RT625ND	JSWX01
Iron	12438 - 30461	na	15/15	na	RT1500W	na
Lead	6.4 - 33.2	2.9 - 9.8	15/15	6/6	RT625ND	JSWX01
Manganese	155.9 - 665.6	na	15/15	na	RT825N	na
Mercury	<0.02 - 0.22	<0.02	10/15	0/6	RT625ND	---
Nickel	21.5 - 38.8	13.7 - 23.8	15/15	6/6	2 stations	MTEC01
Selenium	<3.2 - <8.4	<2.7 - <3.2	0/15	0/6	---	---
Silver	<0.3 - 0.4	<0.2 - <0.3	1/15	0/6	LTBC41	---
Thallium	<12.8 - <33.1	<10.6 - <12.5	0/15	0/6	---	---
Zinc	27.1 - 99.1	20.3 - 30.9	15/15	6/6	RT625ND	JSWX01

na = not analyzed

Metal concentrations were lower in the Alki and intertidal sediments, mainly as a function of the sandy sediments at these stations. Metals have a strong association with fine-grained sediments as demonstrated by Figure 3-11. The strongest associations are seen with aluminum, arsenic, chromium, copper, iron, lead, nickel, and zinc.

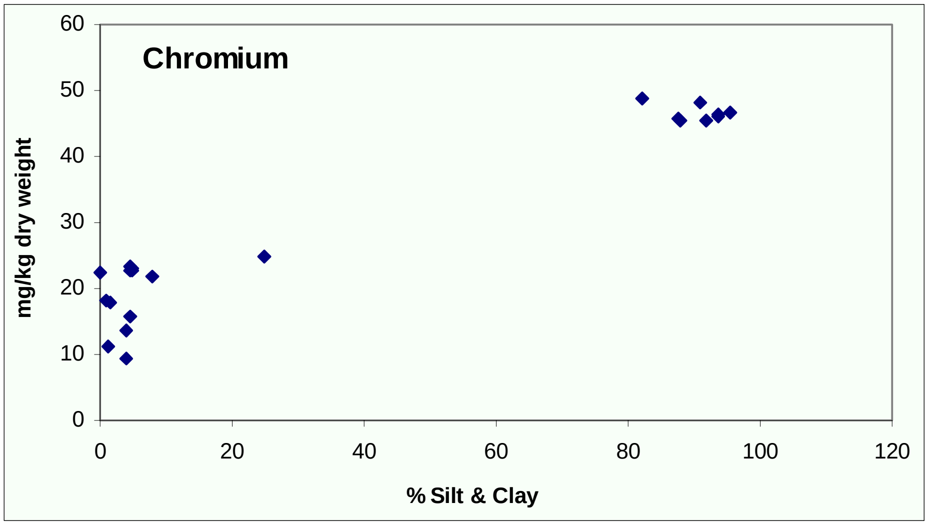

Figure 3-11. Association Between Grain Size and Chromium

Organics A total of 15 subtidal point source stations were monitored for organic compounds. In addition, 6 intertidal stations (3 point source and 3 ambient) were also monitored. Semi-volatile organics (including PAHs), pesticides, and PCBs were measured in all samples.

Dry weight and organic carbon normalized values are presented in Appendix B.

Of the 97 organic compounds analyzed, 18 were above method detection limits in subtidal samples and 7 were above detection limits in intertidal samples. Table 3-4 shows the organic compounds detected and the frequency detected. Most of these compounds were PAHs. PAHs are present in petroleum products and coal-tar related manufacturing products and are byproducts of combustion. PAHs are also found in creosote, a compound used on pilings as a wood preservative. The composition of creosote is approximately eighty-five percent PAHs (Arvin and Flyvbjerg, 1992).

Table 3-4. Organic Compounds Detected in Sediments

Compound	Range (µg/kg) dry weight	Detection Frequency	Station with Highest Value
Subtidal			
1,2,4-Trichlorobenzene	<0.9 - 9.9	1/15	RT700NS
1,4-Dichlorobenzene	<0.9 - 6.7	3/15	RT625ND
1,2-Dichlorobenzene	<0.9 - 3.0	1/15	LTBC41
Anthracene	<21.2 - 67.3	1/15	LTBC41
Benzo(*a*)anthracene	<21.2 - 155.9	9/15	LTBC41
Benzo(*a*)pyrene	<35.7 - 171.3	4/15	LTBC41
Benzo(*b*)fluoranthene	<56.9 - 268.5	1/15	LTBC41
Benzo(*g,h,i*)perylene	<35.7 - 350.2	4/15	RT700NS
Benzo(*k*)fluoranthene	<56.9 - 97.2	1/15	LTBC41
Benzyl butyl phthalate	<21.2 - 30.9	1/15	LTBC41
bis(2-Ethylhexyl)phthalate	<21.2 - 211.4	4/15	LTBC41
Chrysene	<21.2 - 236.1	7/15	LTBC41
di-*n* -Butyl phthalate	<35.7 - 38.5	1/15	AL343S
Fluoranthene	<21.2 - 245.4	9/15	LTBC41
Hexachlorobenzene	<0.1 - 2.5	3/15	RT700NS
Hexachloroethane	<35.1 - 101.0	1/15	RT700NS
Indeno(1,2,3-*cd*)pyrene	<35.7 - 135.6	4/15	RT700NS
Phenanthrene	<21.2 - 119.6	2/15	LTBC41
Pyrene	<21.2 - 240.7	9/15	LTBC41
Intertidal			
Benzo(*a*)anthracene	<16.7 - 32.5	1/16	KSSN04
Benzo(*a*)pyrene	<28.2 - 38.7	1/16	KSSN04
Chrysene	<16.7 - 23.7	1/16	KSSN04
Fluoranthene	<16.7 - 61.4	2/16	KSSN04
Hexachlorobenzene	<0.72 - 1.6	1/16	KSSN04
Phenanthrene	<16.7 - 39.3	1/16	KSSN04
Pyrene	<16.7 - 64.2	1/16	KSSN04

The Alki and intertidal stations which had a high sand and gravel content had fewer compounds detected than the Renton and waterfront stations. With the exception of fluoranthene that was detected at two stations, the only intertidal station where organics were detected was the station on the north side of West Point, KSSN04. Of all the subtidal stations, the highest concentrations were found at LTBC41 the majority of the time. This station is located in inner Elliott Bay where high PAHs and other organic compounds have historically been found.

Several subtidal (the six Alki stations) and all the intertidal stations had low organic carbon values (< 0.45 %) due to the sandy nature of the sediments in these areas. Due to the low organic carbon content at these stations, it is not appropriate to use organic carbon normalized values to assess compliance with regulatory standards that are organic carbon based. For these stations, dry weight values are more appropriate for comparison with regulatory standards that are based upon apparent effects thresholds (AETs). Although hexachlorobutadiene and N-nitrosodiphenylamine were not detected in either the Alki or intertidal stations, the method detection limits exceeded the AETs for these compounds. Also not detected in the Alki and intertidal stations was 2,4-dimethylphenol, however, the detection limit exceeded the SQS. It is very difficult to obtain low detection limits for these compounds.

The subtidal samples collected off the Renton Treatment Plant outfall were composed of mainly silt and clay and had organic carbon values over 2.5 %, therefore organic carbon normalized values can be compared to SQSs where appropriate. Hexachlorobenzene exceeded the SQS for three stations (RT625ND, RT700NS, and RT625SD) and the cleanup screening level at RT700NS. These three stations are located at and between the two diffuser pipes. Hexachlorobenzene was not detected at Renton outfall stations sampled previously and the source is not clear. No other detected compounds exceeded existing standards. Although 2,4-dimethyphenol, 2-methylphenol, and benzyl alcohol were not detected, the method detection limits were above the SQSs for these compounds. As stated above for 2,4-dimethylphenol, it is very difficult to obtain detection limits lower than the standards for these compounds. No pesticides or PCBs were detected in any of the samples.

Bacteria in Sediment Fecal coliform and *enterococcus* bacteria were monitored three times (April, July, and October) at six intertidal stations; three point source and three ambient. Station KSXS02 near Magnolia had the highest fecal coliform and *enterococcus* levels of the stations monitored with values ranging from < 20 to 1300 MPN/100g. This station tends to be affected by freshwater runoff as currents carry water from the Duwamish River and inner Elliott Bay by the Magnolia nearshore area. The highest values were found in April as two days prior to the April sample collection, 1.4 inches of rain fell. Fecal coliform levels reflect the influence from freshwater runoff at those stations near a freshwater source, KSXS02 near Magnolia and KSHZ03 near Piper's Creek in Carkeek Park. Sediment standards for fecal coliform bacteria do not currently exist, therefore, comparisons with standards cannot be made.

Shellfish Data

Shellfish samples were collected from intertidal beaches as a part of the ambient and point source monitoring programs and consisted of the most prevalent edible species. Whole tissue samples consisted either entirely or a combination of the following: native littleneck (*Protothaca staminea*), manila (*Venerupis philippinarum*), butter (*Saxidomus giganteus*), horse (*Tresus capax*), and *Macoma sp.* clams. *Macoma sp*. clams were only collected when other species were not available as this is a surface deposit feeder whereas all other species collected are filter feeders. Different feeding strategies can affect the results, thus direct comparisons between results and stations cannot be made.

Point source samples were analyzed for semi-volatile organics, pesticides, PCBs, metals, fecal coliform and *enterococcus* bacteria. Ambient samples were analyzed for fecal coliform and *enterococcus* bacteria only. All results are presented on a wet weight basis. All tissue data are provided in Appendix C.

Results

Two point source stations were sampled for metals, organic compounds (including PAHs, pesticides, and PCBs), fecal coliform and *enterococcus* bacteria. One point source and five ambient sites were monitored for fecal coliform and *enterococcus* bacteria only.

Metals Thirteen metals were analyzed at KSSN04 near West Point and LSKR01 near Alki Point. Antimony, beryllium, lead, selenium, and thallium were below the MDLs for both samples. These metals, with the exception of lead, were also below the MDLs in previous years monitoring. Concentrations of arsenic, cadmium, chromium, mercury, nickel, silver, and zinc detected varied only slightly between both samples and were similar to values detected in shellfish collected in 1996 and from previous studies (King County, 1998; NOAA, 1981). Copper was detected at station LSKR01 in 1996 but was below detection limits in 1997. At station KSSN04, the copper concentration was 2.55 mg/kg, which is lower than the concentration detected in 1996.

State and federal criteria do not exist for acceptable levels of metals in shellfish tissues. However, the U.S. Food and Drug Administration (FDA) has established guidance values termed Levels of Concern for mollusks for five metals: arsenic, cadmium, chromium, lead, and nickel. These guidance values are risk-based and differ for children and adults. For comparative purposes, the lowest of the two values was chosen. Results from King County monitoring were below Levels of Concern for arsenic (55 mg/kg), cadmium (3 mg/kg), chromium (11 mg/kg), lead (0.8 mg/kg), and nickel (80 mg/kg) (FDA 1993a,b,c,d,e).

The FDA has established an Action Level in fish and shellfish tissues of 1.0 mg/kg for mercury (FDA, 1995). When this value is exceeded, the food product cannot be commercially traded which is how an Action Level differes from a Level of Concern. Mercury concentrations were well below this Action Level. A summary of concentrations detected in shellfish are given in Table 3-5.

Organics The same two stations that were monitored for metals were also monitored for organics, which included semi-volatile organics, pesticides and PCBs. Of all the compounds analyzed, only the following compounds were detected: benzoic acid, benzyl alcohol, 2-methylphenol, and pyrene. Benzoic acid was detected at concentrations ranging from 4,390 to 5,150 mg/kg. Benzoic acid is used as a food preservative and an anti-fungal agent, however, it is also a degradation product produced by

Table 3-5. Metals Summary, Stations KSSN04 & LSKR01

	Range (mg/kg wet weight)	
	1996	**1997**
Antimony	<0.3	<0.3
Arsenic	3.1 - 3.4	3.0 - 3.2
Beryllium	<0.01	<0.01
Cadmium	0.08 - 0.09	0.06 - 0.07
Chromium	0.40 - 0.44	0.35 - 0.50
Copper	0.54 - 4.72	<0.04 - 2.6
Lead	<0.3	<0.3
Mercury	0.007 - 0.012	0.009 - 0.013
Nickel	0.78 - 0.92	0.90 - 1.13
Selenium	<0.5	<0.5
Silver	0.97 - 2.18	1.50 - 1.80
Thallium	<2.0	<2.0
Zinc	12.7 - 14.3	13.8 - 14.2

metabolic processes and has always been detected in shellfish samples in the past. Benzyl alcohol was detected at both stations, ranging from 88 to 101 mg/kg. Benzyl alcohol is used for a variety of purposes, including a solvent for gelatin and flavoring manufacturing, cosmetics, ball point pen inks and other dyes, and as a preservative for many drugs, ointments, and dental solutions. Concentrations of 2-methylphenol ranged from 33 to 65 mg/kg and were similar to values found from previous sampling. Pyrene was detected at station KSSN04 at a concentration just above the method detection limt. No pesticides or PCBs were detected in any of the samples.

Fecal Coliform Bacteria in Shellfish Fecal coliform and *enterococcus* bacteria were monitored at five ambient stations and eight compliance stations. All ambient stations and three compliance stations were sampled from May to September. Five compliance stations were sampled in July only. The results can be found in Appendix C.

Fecal coliform concentrations varied from station to station and from month to month. Generally, stations near Tramp Harbor (MSSM05) and Seahurst Park (MTEC01) had the lowest levels with values ranging from 50 to 1300 MPN/100g. The highest levels (11,000 MPN/100g) were found in September at station KSLU03 located at the north end of Golden Gardens and north of the Lake Washington Ship Canal. This station is affected from freshwater runoff from the Ship Canal and about 0.5 inches of rain fell the day the sample was collected. Fecal coliform counts were generally the highest in September. Counts also tended to be higher in August, which may be due to increased bacteria concentrations as the die-off rate decreases and/or sources increase. The two stations located near West Point and Alki Point were only sampled in July, therefore, comparisons between stations and months cannot be made for these sites. *Enterococcus* bacteria counts were not correlated with fecal coliform counts and the highest concentrations were not found in any particular month.

The Washington State Department of Health (DOH) uses three categories to assess fecal coliform contamination in shellfish tissue (PSWQAT, 1998):

> Low or undetectable levels of contamination: Less than 30 organisms/100g,
>
> Moderate levels of contamination: Between 30-230 organisms/100g,
>
> Unhealthy levels of contamination: Greater than 230 organisms/100g.

There are limitations of using this categorization for shellfish samples taken at ambient and point source beaches as only five samples were analyzed annually and the samples were not composed entirely of the same species. However, very general comparisons can be made for the five beaches sampled from May to September. For shellfish collected from and Carkeek Park (KSHZ03), Tramp Harbor (MSSM05), and Seahurst Park (MTEC01), the majority of the values were between 30 and 230 organisms/100g. For stations at Fay Bainbridge (KRJY01) and Golden Gardens (KSLU03), all values measured were greater than 230 organisms/100g.

There does not appear to be a relationship between the fecal coliform concentrations measured in shellfish and the concentrations detected in water. Stations with shellfish bacteria values over 230 organisms/100g had corresponding geometric mean water concentrations less than 14 cfu/100ml and conversely, stations with the majority of values falling between 30 and 230 organisms/100g had corresponding geometric mean water concentrations over 14 cfu/100ml. Figure 3-12 shows the lack of a relationship between fecal coliform concentrations measured in water and shellfish, and the amount of rainfall that fell in a three-day period prior to sampling. Although several other studies have also found that a constant association between fecal coliform concentrations in shellfish and overlying water does not exist, shellfish from waters meeting water quality criteria are unlikely to be involved in the spread of disease (NSSP, 1995).

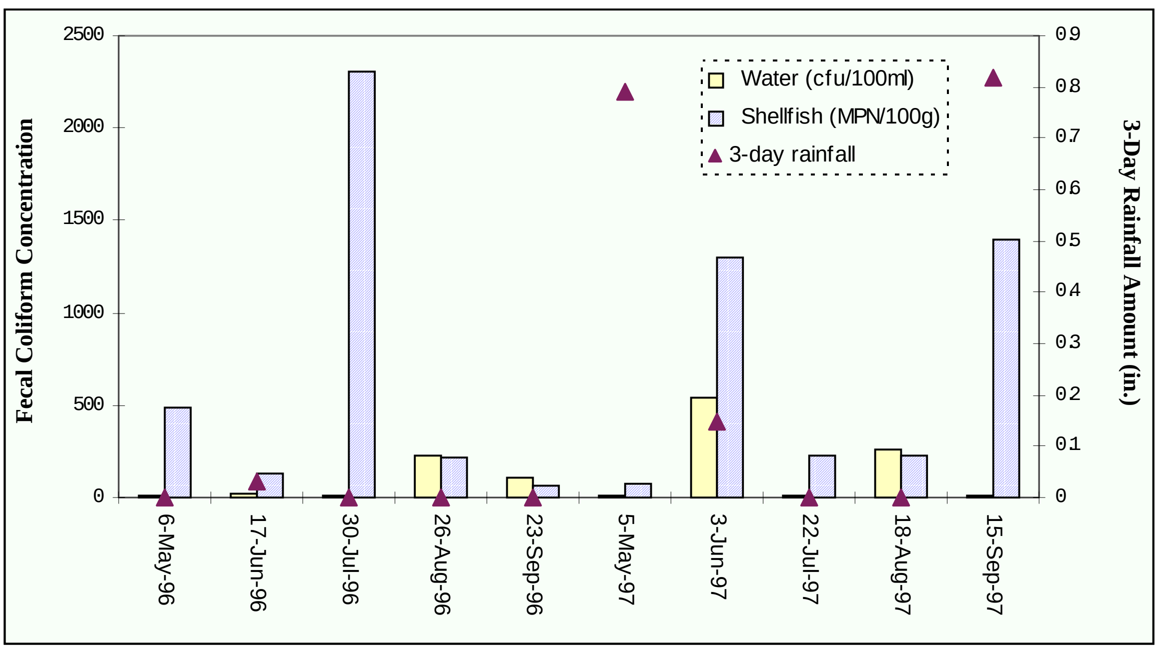

Figure 3-12. Fecal Coliform Values for Water and Shellfish from Station KSHZ03

Macroalgae Data

Macroalgae (algae) samples were collected from intertidal beaches and consisted entirely of the most prevalent edible algae, *Ulva fenestrata* (known as sea lettuce). Samples were analyzed for metals only. All macroalgae data is presented on a wet weight basis and can be found in Appendix D.

Results

Algae from three point source and one ambient sites were sampled for metals: two at West Point, one at Alki Point, and one at Magnolia. Two stations were sampled in July (KSSN04 and LSKR01) and the other two were sampled in October (KSSN05 and KSUR01). The latter two stations mentioned above were sampled after the results from station KSSN04 were obtained and reviewed. Stations KSSN04 and KSSN05 are on the north and south side of West Point, respecitively. Stations near West Point have had higher concentrations for some metals than others sampled over the past few years, and since KSSN05 was not initally sampled with the other two stations, it was decided that this station as well as another station should be sampled.

Macroalgae samples were monitored for thirteen metals. Antimony, mercury, selenium, and thallium were below the MDLs in all samples. Beryllium and silver were detected at station LSKR01 at concentrations just slightly above the detection limits and lead was found at KSSN05 and KSUR01 just above the detection limit. Arsenic, chromium, copper, nickel, and zinc were detected in all samples. Cadmium was detected at KSSN04, LSKR01, and KSUR01 but not KSSN05. Station KSSN05, located just south of the Coast Guard lighthouse near West Point, had the highest concentrations of chromium, copper, lead, nickel, and zinc. This station, as well as KSSN04 which is just north of the lighthouse, also had high concentrations of these metals relative to the station sampled at Alki Point. This is the same pattern observed in recent years for these two stations, particularly KSSN04. A summary of metal concentrations detected in algae samples from 1993 to 1997 is given in Table 3-6.

To determine if the pattern of higher metals near West Point is a continuing event, macroalgae will be sampled at additional stations in 1999. These stations will be located on both the west and east side of the central basin as well as north and south of West Point. In addition, total and dissolved metals will be measured in the water column at several stations, including the West Point stations.

Table 3-6. Metal Concentrations in Macroalgae

	1997		1996		1995		1994		1993	
	KSSN04 & KSSN05	LSKR01 & KSUR01	KSSN04 & KSSN05	All Other Stations *	KSSN04 & KSSN05	All Other Stations	KSSN04 & KSSN05	All Other Stations	KSSN04 & KSSN05	All Other Stations
Arsenic	0.89 - 1.1	0.91 - 0.98	0.66 - 0.94	<0.50	<0.50 - 0.53	<0.05 - 0.67	<1.0 - 1.1	<1.0 - 1.6	0.5 - 0.7	<0.5 - 0.8
Cadmium	<0.03 - 0.05	0.06 - 0.1	0.05 - 0.06	<0.03 - 0.05	<0.03 - 0.06	<0.03 - 0.11	<0.06	<0.06 - 0.06	0.06	0.04 - 0.07
Chromium	1.05 - 2.08	0.07 - 0.13	1.50 - 4.08	0.05 - 0.44	2.27 - 5.25	0.53 - 3.81	1.01 - 1.18	0.28 - 7.37	1.40 - 5.50	0.42 - 2.00
Copper	2.43 - 3.31	0.76 - 2.17	1.15 - 43.0	0.28 - 12.40	3.41 - 14.20	0.80 - 5.88	0.90 - 0.94	0.99 - 6.76	1.20 - 4.80	0.77 - 13.00
Lead	<0.3 - 0.35	<0.3 - 0.48	0.38 - 1.90	<0.3 - 0.56	0.44 - 0.61	<0.3 - 0.79	<0.6	<0.6 - 0.6	<0.3 - 0.7	<0.3 - 0.4
Nickel	1.32 - 2.48	0.36 - 0.75	1.25 - 8.28	<0.20 - 0.55	6.48 - 9.44	0.62 - 3.31	0.96 - 1.6	0.79 - 4.26	1.30 - 4.40	0.50 - 2.10
Zinc	2.76 - 3.98	0.8 - 2.86	1.73 - 20.50	0.56 - 5.92	5.67 - 8.01	1.02 - 3.90	1.76 - 1.80	1.36 - 3.77	1.70 - 4.50	1.50 - 4.50

Note: Antimony, beryllium, mercury, selenium, silver, and thallium values are not presented as these metals were either not detected or seldom detected.

* Other stations include KSHZ03, KSJX02, KSLU03, KSUR01, LSKR01, and LSKS01.